Chapel: Productive Parallel Programming at all Scales

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SSEC, eScience Institute, University of Washington
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What is Chapel?

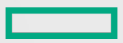
Chapel: A modern parallel programming language

- Portable & scalable
- Open-source & collaborative
  - an HPSF / Linux Foundation project

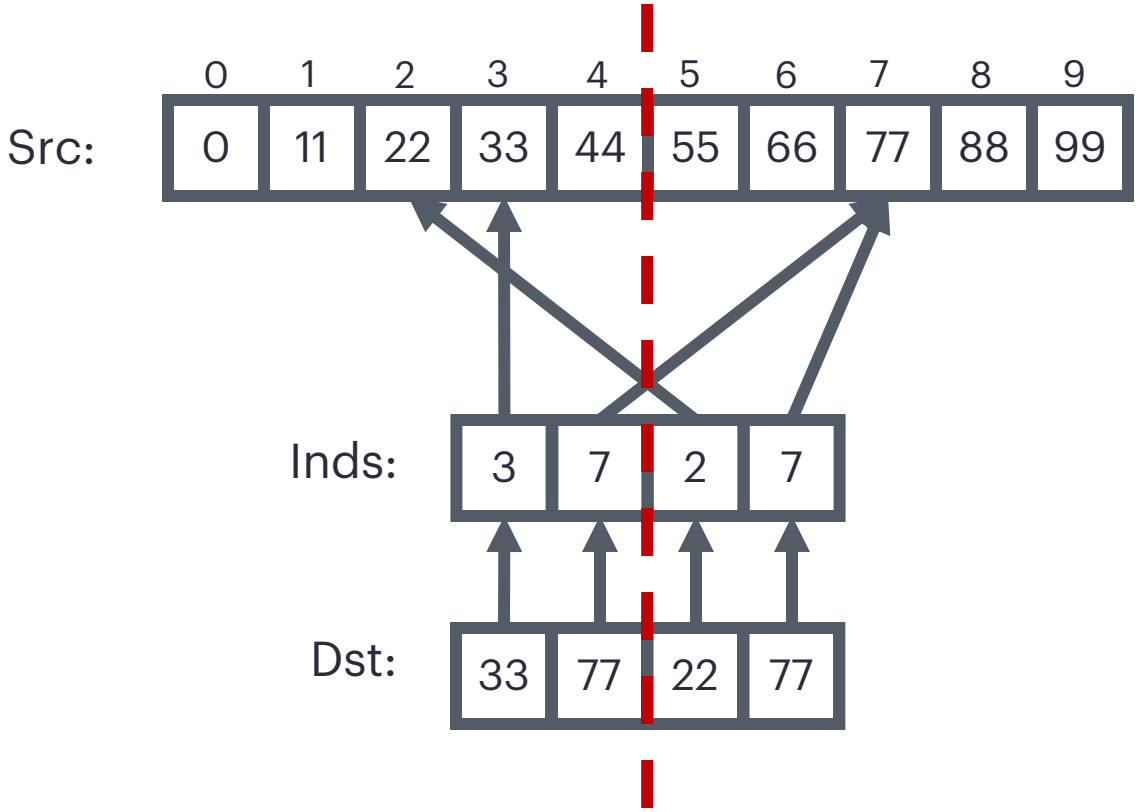
Goals:

- Support general parallel programming
- Make parallel programming at scale far more productive

Chapel By Example: Bale Index Gather

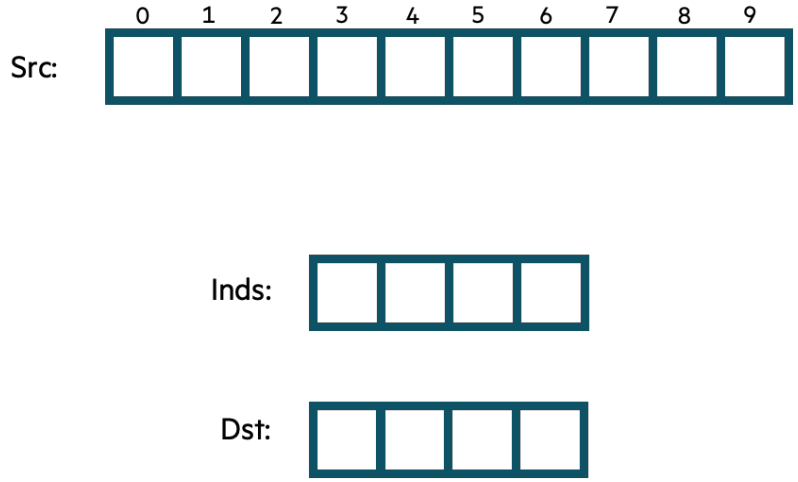


Bale Index Gather (IG): In Pictures



Bale IG in Chapel: Scalar and Array Declarations

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
```

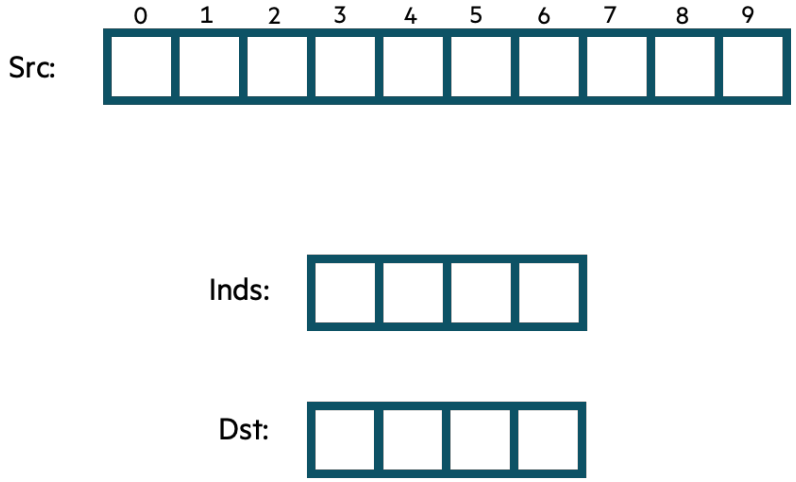



```
$
```

Bale IG in Chapel: Compiling

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
```

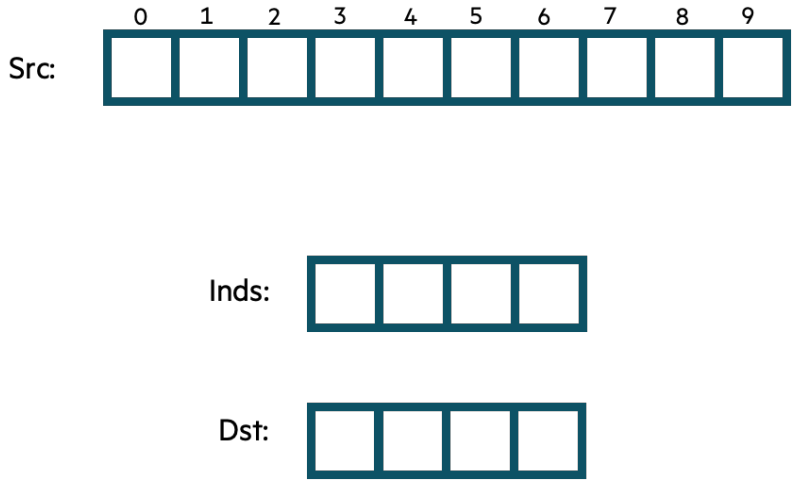
```
$ chpl bale-ig.chpl
$
```

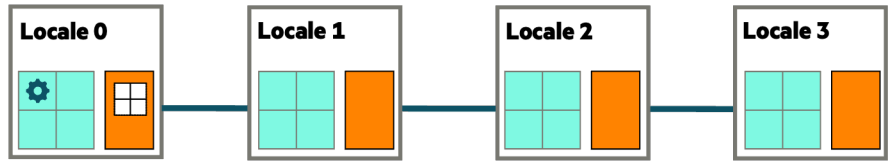


Bale IG in Chapel: Executing

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
```

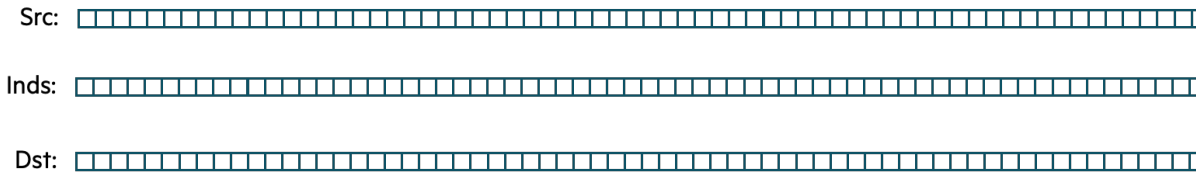
```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```



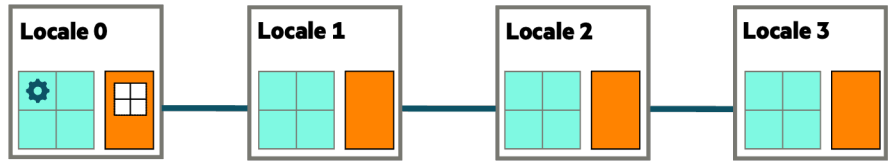


Bale IG in Chapel: Executing, Overriding Configs

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
```



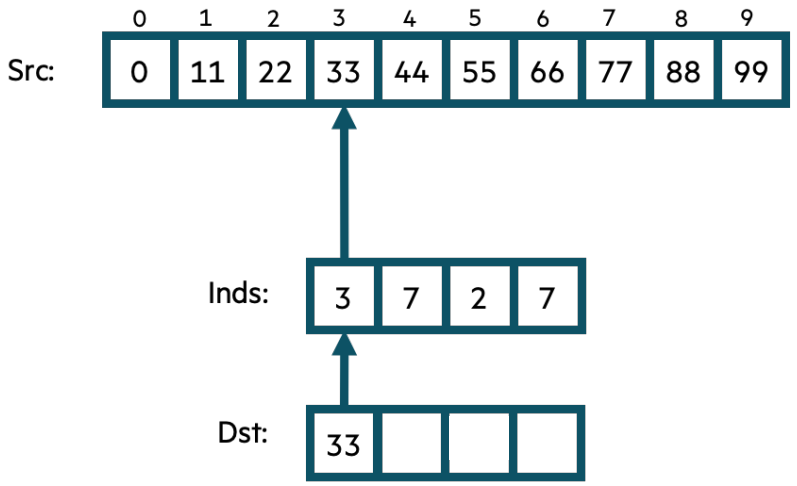

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4 --n=1_000_000 --m=1_000_000
$
```

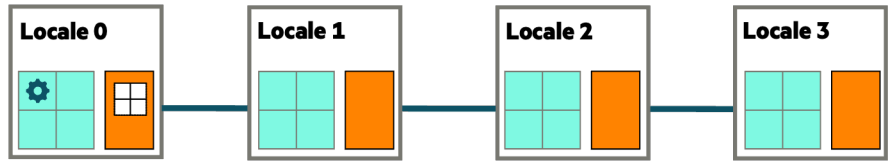


Bale IG in Chapel: Serial, Zippered Version

```
config const n = 10,
             m = 4;




var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
for (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```

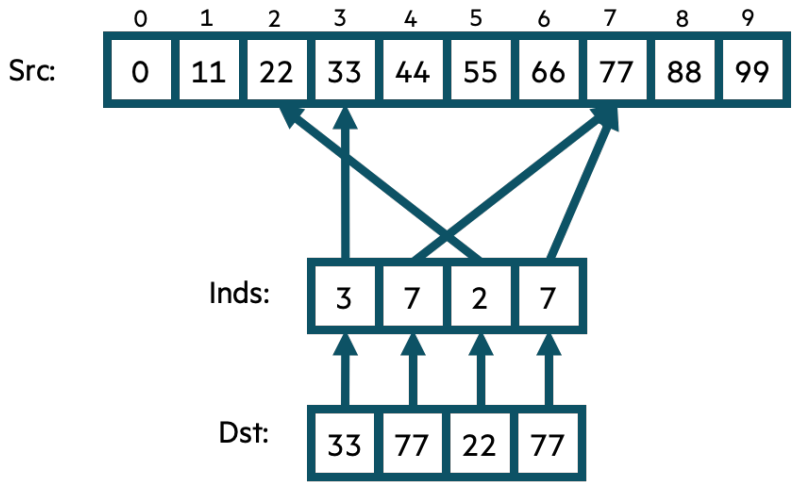


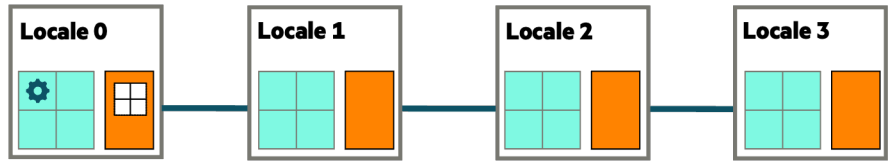


Bale IG in Chapel: Parallel, Zippered Version (vectorized)

```
config const n = 10,
             m = 4;




var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
foreach (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

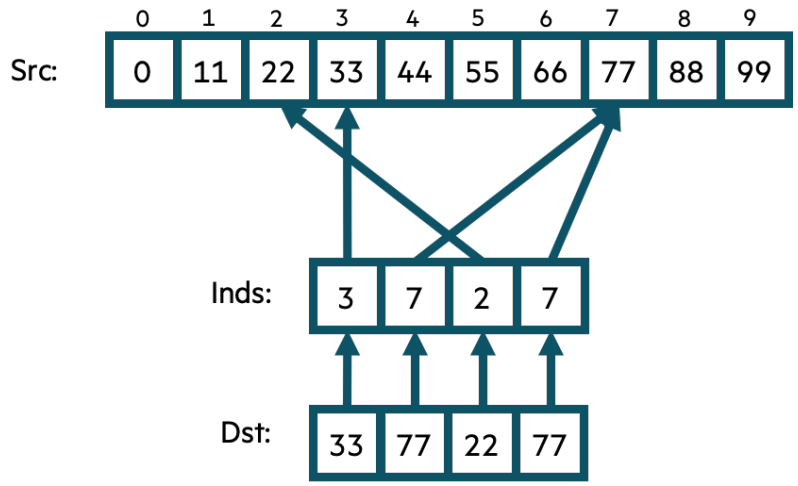
```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```



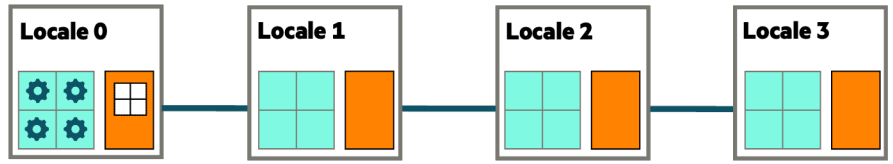


Bale IG in Chapel: Parallel, Zippered Version (multicore)

```
config const n = 10,
             m = 4;




var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

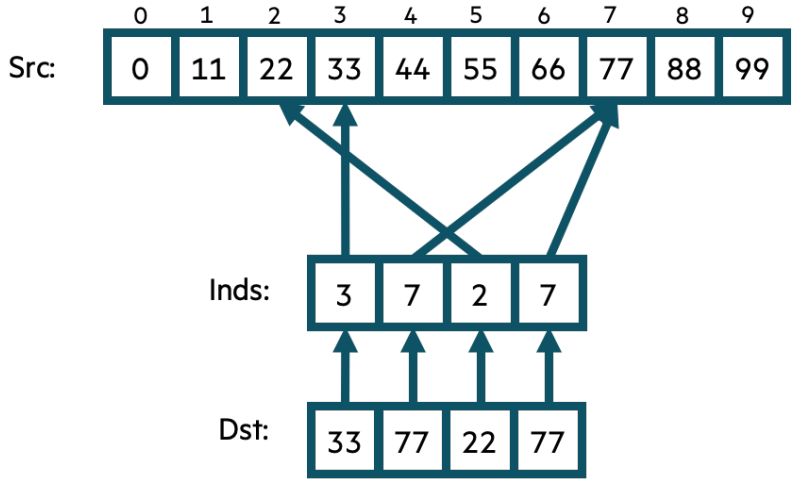



```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```

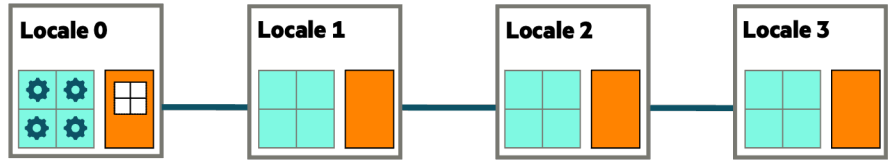


Bale IG in Chapel: Parallel Promoted Version (equivalent to previous version)

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
Dst = Src[Inds];
```

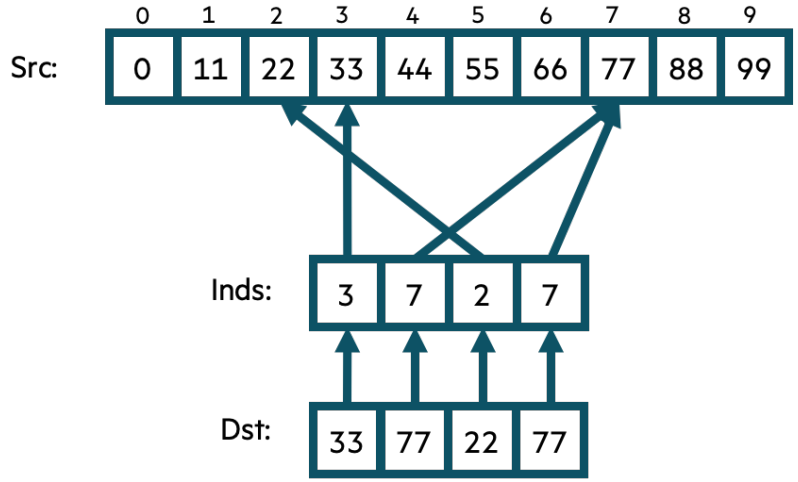



```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```

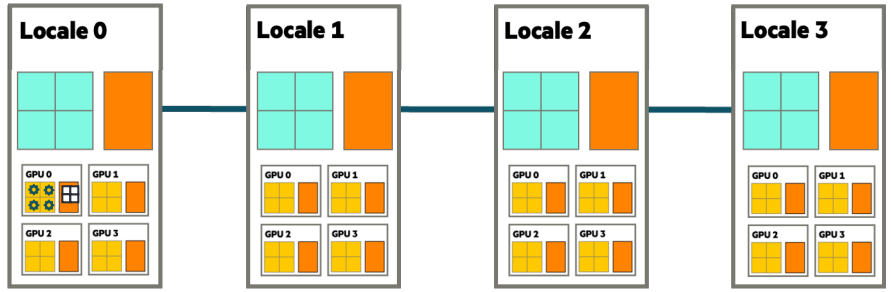


Bale IG in Chapel: Parallel, Zippered Version (single GPU)

```
config const n = 10,
             m = 4;


on here.gpus[0] {
  var Src: [0..<n] int,
      Inds, Dst: [0..<m] int;
  …
  Dst = Src[Inds];
}
```

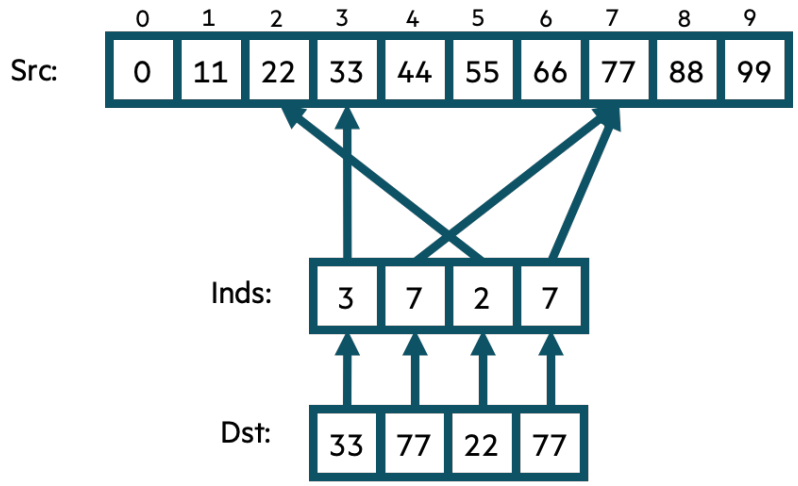



```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```

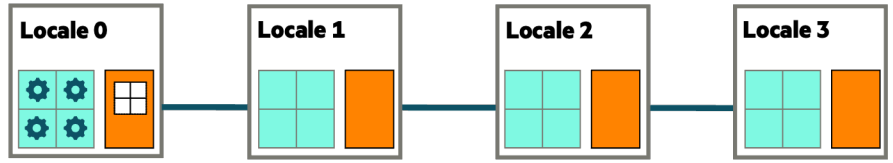


Bale IG in Chapel: Parallel, Zippered Version (Multicore, again)

```
config const n = 10,
             m = 4;




var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

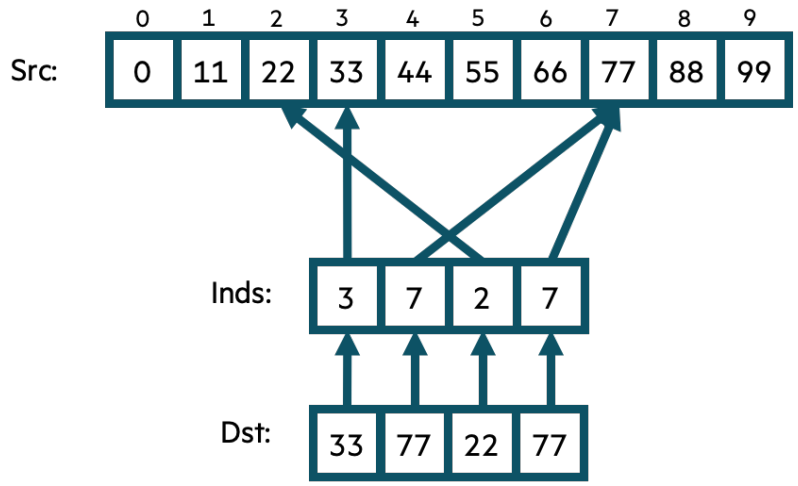



```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```

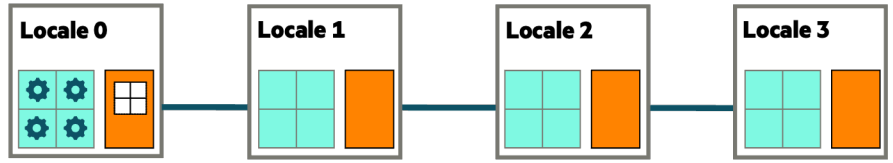


Bale IG in Chapel: Parallel, Zippered Version with Named Domains (Multicore)

```
config const n = 10,
             m = 4;

const SrcInds = {0..<n},
      DstInds = {0..<m};

var Src: [SrcInds] int,
    Inds, Dst: [DstInds] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

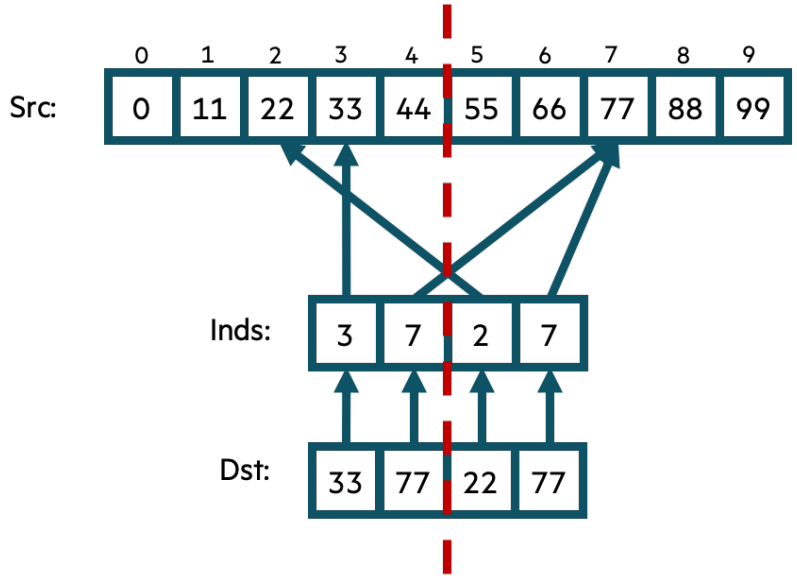



```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```

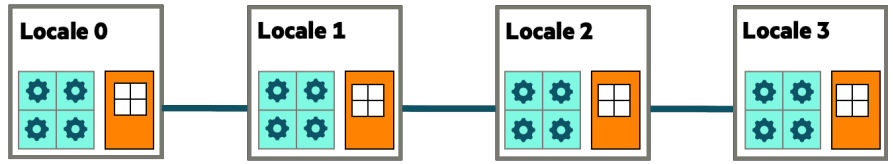


Bale IG in Chapel: Distributed Parallel Version

```
use BlockDist;

config const n = 10,
             m = 4;

const SrcInds = blockDist.createDomain(0..<n),
      DstInds = blockDist.createDomain(0..<m);

var Src: [SrcInds] int,
    Inds, Dst: [DstInds] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

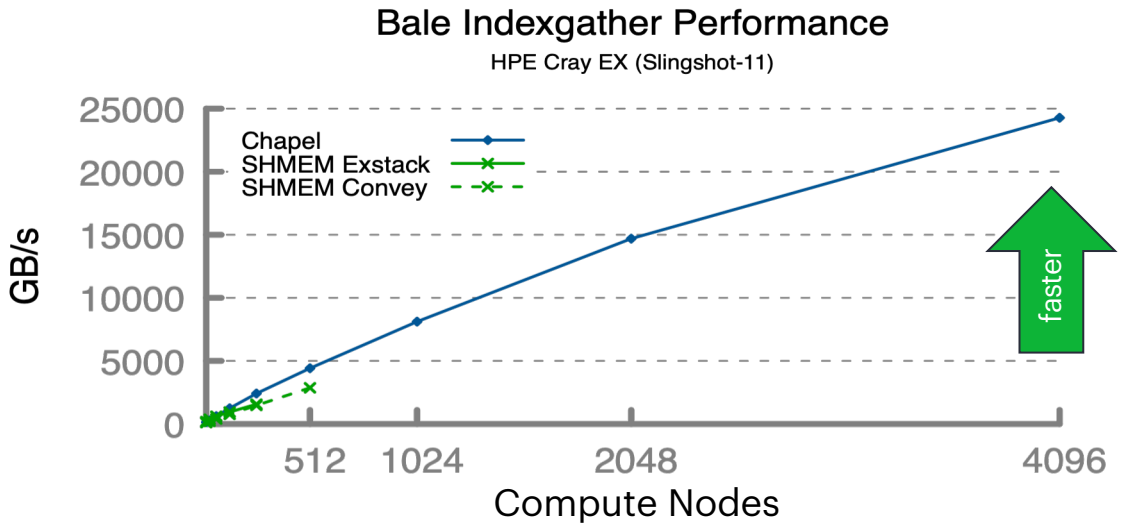



```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```



Bale IG in Chapel: Distributed Parallel Version on HPE Cray EX

```
use BlockDist;

config const n = 10,
             m = 4;

const SrcInds = blockDist.createDomain(0..<n),
      DstInds = blockDist.createDomain(0..<m);

var Src: [SrcInds] int,
    Inds, Dst: [DstInds] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```




```
$ chpl bale-ig.chpl --fast --auto-aggregation
$ ./bale-ig -nl 4096 --n=… --m=…
$
```

Bale IG in Chapel vs. SHMEM on HPE Cray EX

Chapel

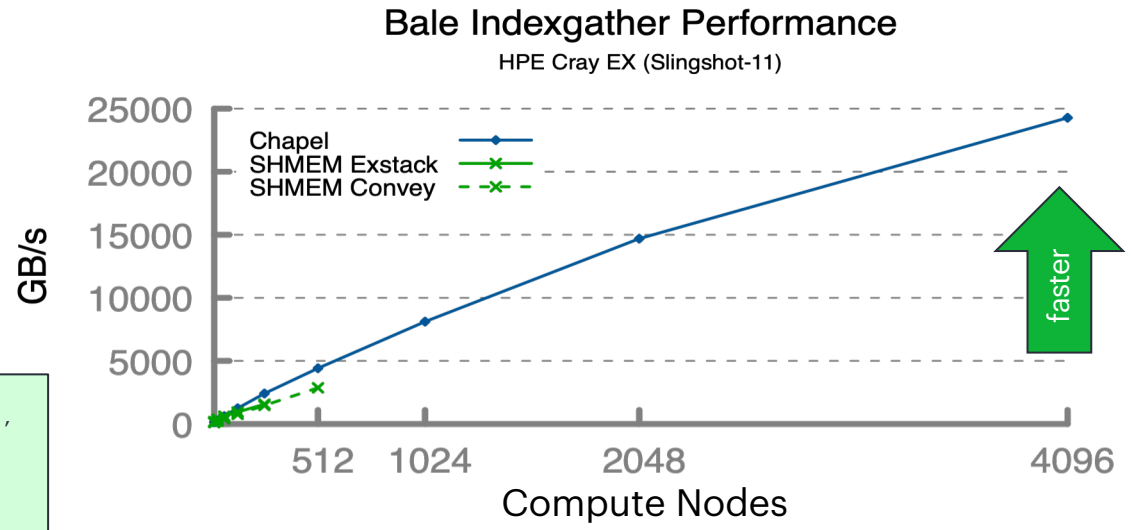
```
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

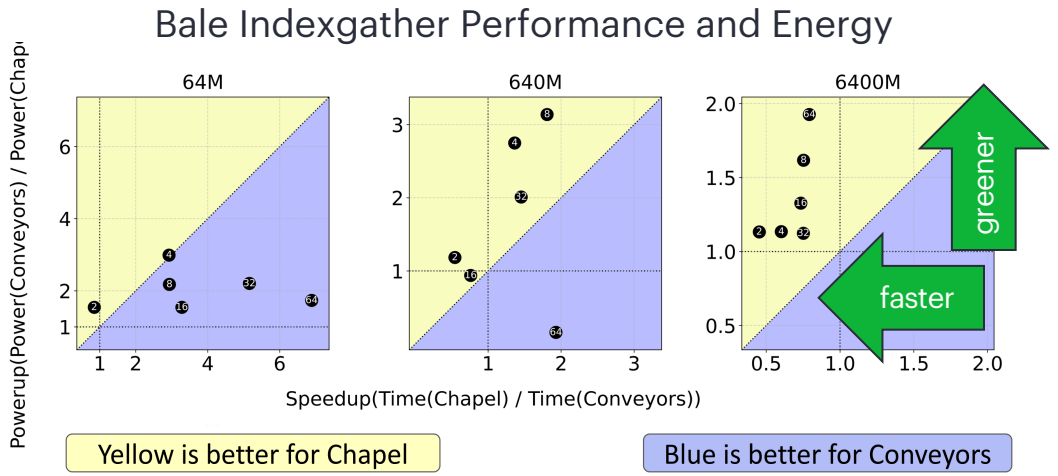
SHMEM (Exstack version)

```
i=0;
while( exstack_proceed(ex, (i==l_num_req)) ) {
  i0 = i;
  while(i < l_num_req) {
    l_indx = pckindx[i] >> 16;
    pe  = pckindx[i] & 0xffff;
    if(!exstack_push(ex, &l_indx, pe))
      break;
    i++;
  }

  exstack_exchange(ex);

  while(exstack_pop(ex, &idx , &fromth)) {
    idx  = ltable[idx];
    exstack_push(ex, &idx, fromth);
  }
  lgp_barrier();
  exstack_exchange(ex);

  for(j=i0; j<i; j++) {
    fromth = pckindx[j] & 0xffff;
    exstack_pop_thread(ex, &idx, (uint64_t)fromth);
    tgt[j] = idx;
  }
  lgp_barrier();
}
```

SHMEM (Conveyors version)

```
i = 0;
while (more = convey_advance(requests, (i == l_num_req)),
       more | convey_advance(replies, !more)) {

  for (; i < l_num_req; i++) {
    pkg.idx = i;
    pkg.val = pckindx[i] >> 16;
    pe = pckindx[i] & 0xffff;
    if (! convey_push(requests, &pkg, pe))
      break;
  }

  while (convey_pull(requests, ptr, &from) == convey_OK) {
    pkg.idx = ptr->idx;
    pkg.val = ltable[ptr->val];
    if (! convey_push(replies, &pkg, from)) {
      convey_unpull(requests);
      break;
    }
  }

  while (convey_pull(replies, ptr, NULL) == convey_OK)
    tgt[ptr->idx] = ptr->val;
}
```





[performance x energy results from *Heading Towards Energy Savings or Just Performance: Case-Study on Message Aggregation-Based Runtimes,* Shubhendra Pal Singhal et al., CUG 2026, April 28, 2026]

There's lots more to Chapel…

Additional parallel features:

- multidimensional, associative, and sparse arrays
- explicit task-based parallelism
- variables for synchronized data sharing
- reduction and scan operators
- …

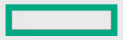
Additional scalability features:

- explicit control over placement of data and tasks
- a global namespace
- the ability to reason about location
- …

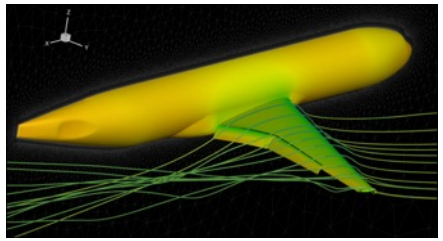
Additional base language features:

- OOP (value- and reference-based)
- modules for namespacing
- overloading, rich arguments, generics
- type inference
- memory safety
- …

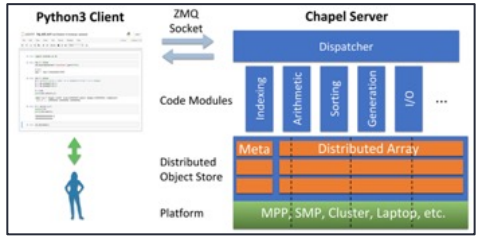
Applications of Chapel / Arkouda



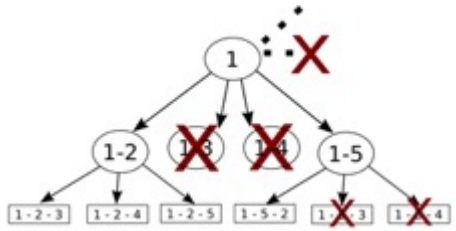
Applications of Chapel



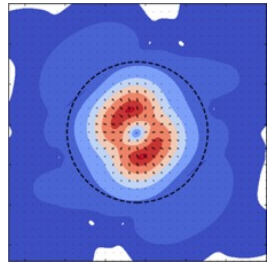
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



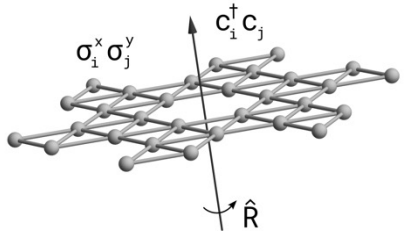
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



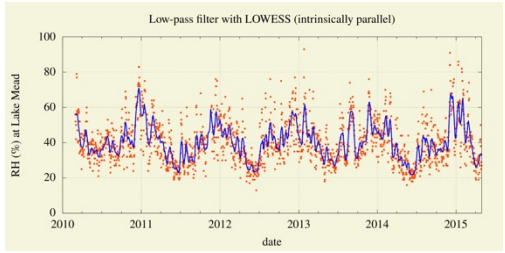
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



ChplUltra: Simulating Ultralight Dark Matter
Nikhil Padmanabhan, J. Luna Zagorac, et al.
Yale University et al.

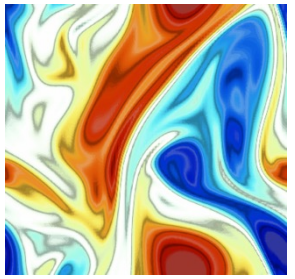


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

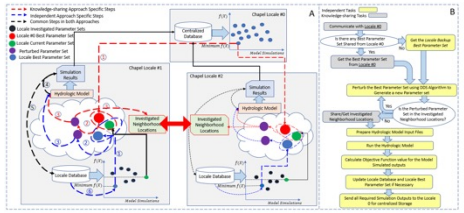


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

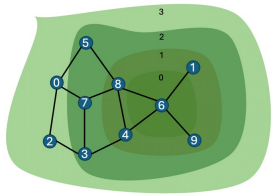
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



ChapQG: Layered Quasigeostrophic CFD
Ian Grooms and Scott Bachman
University of Colorado, Boulder et al.

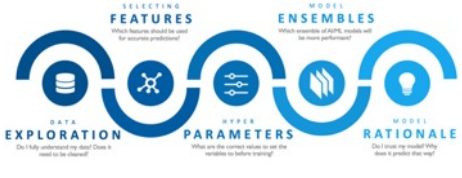


Chapel-based Hydrological Model Calibration
Marjan Asgari et al.
University of Guelph



Arachne Graph Analytics
Bader, Du, Rodriguez, et al.
New Jersey Institute of Technology

Modeling Ocean Carbon Dioxide Removal
Scott Bachman Brandon Neth, et al.
[C]Worthy



CrayAI HyperParameter Optimization (HPO)
Ben Albrecht et al.
Cray Inc. / HPE

[images provided by their respective teams and used with permission]

Data Science In Python at scale?

Motivation: Imagine you have...

...Python-based data scientists

...HPC-scale data science problems to solve

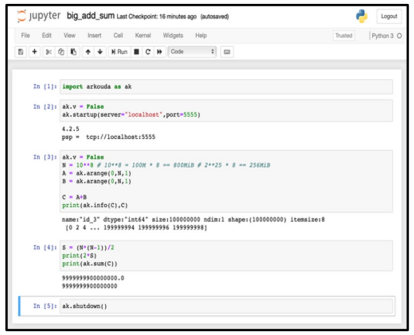
...access to HPC systems

How will you enable your Python programmers to get their work done?

What is Arkouda?

Q: “What is Arkouda?”

Arkouda Client
(written in Python)



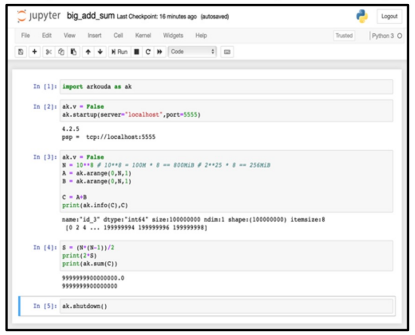
```
import arkouda as ak

def ak_argsort(N, seed):
    a = ak.randint(0, 2**64, N, dtype=ak.uint64, seed=seed)
    perm = ak.argsort(a)

    assert ak.is_sorted(a[perm])
```

User writes Python code
making familiar NumPy/Pandas calls

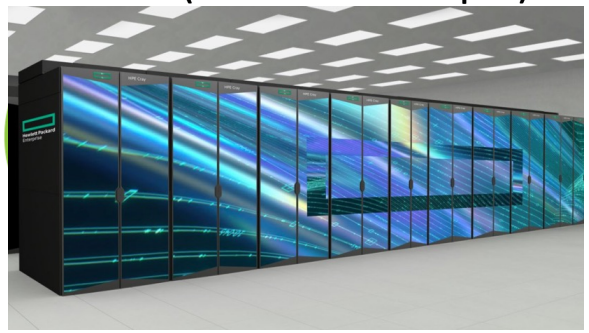
What is Arkouda?

Q: “What is Arkouda?”

Arkouda Client
(written in Python)



Arkouda Server
(written in Chapel)



User writes Python code
making familiar NumPy/Pandas calls

```
import arkouda as ak

def ak_argsort(N, seed):
    a = ak.randint(0, 2**64, N, dtype=ak.uint64, seed=seed)
    perm = ak.argsort(a)

    assert ak.is_sorted(a[perm])
```

A1: “A scalable version of NumPy / Pandas routines for data scientists”

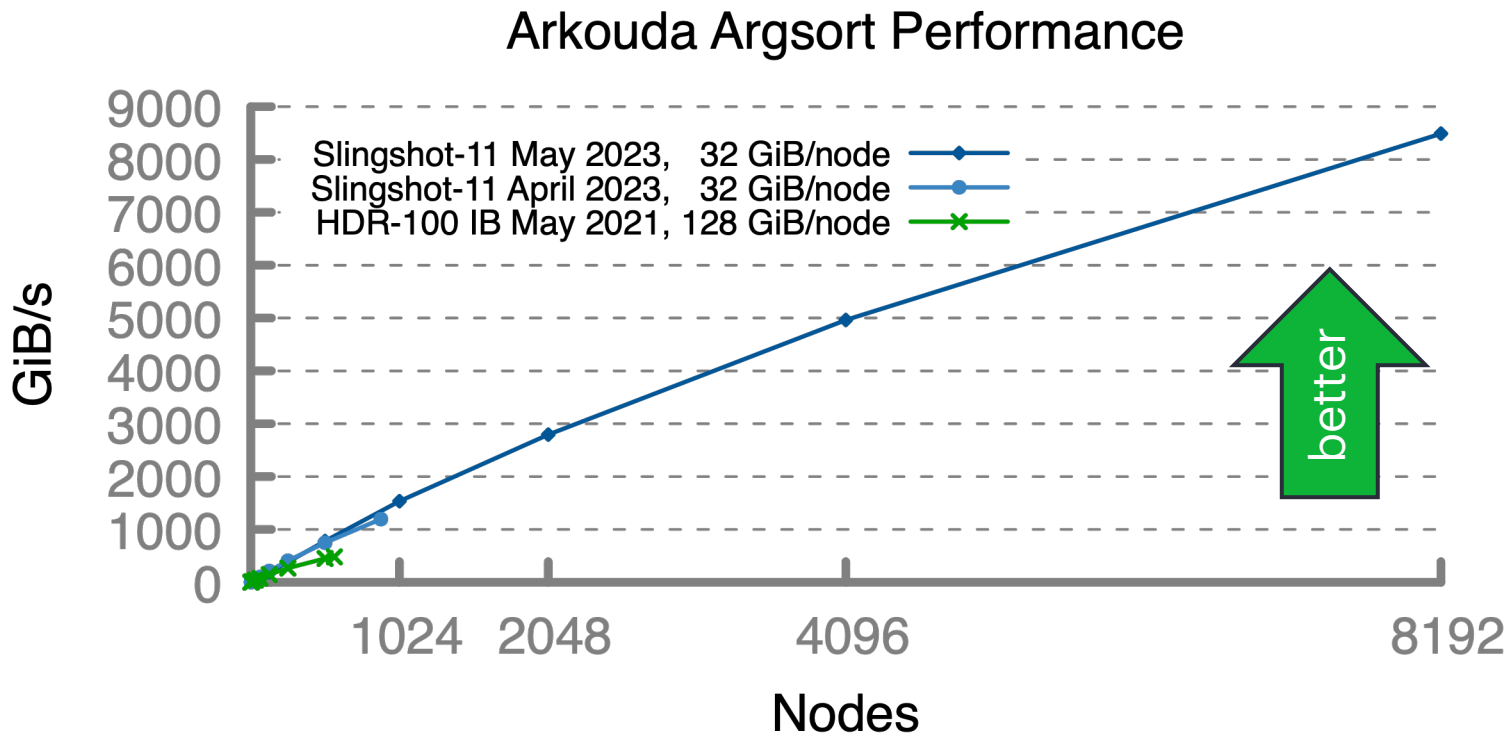
A2: “A framework for driving supercomputers interactively from Python”

Performance and Productivity: Arkouda Argsort

HPE Cray EX
- Slingshot-11 network (200 Gb/s)
- 8192 compute nodes
- 256 TiB of 8-byte values
- ~8500 GiB/s (~31 seconds)

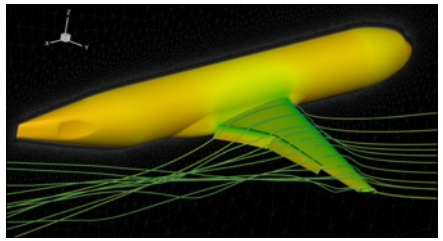
HPE Cray EX
- Slingshot-11 network (200 Gb/s)
- 896 compute nodes
- 28 TiB of 8-byte values
- ~1200 GiB/s (~24 seconds)

HPE Apollo
- HDR-100 InfiniBand network (100 Gb/s)
- 576 compute nodes
- 72 TiB of 8-byte values
- ~480 GiB/s (~150 seconds)

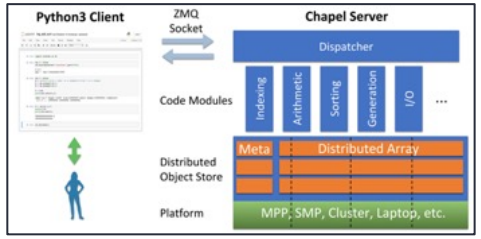


Implemented using ~100 lines of Chapel code

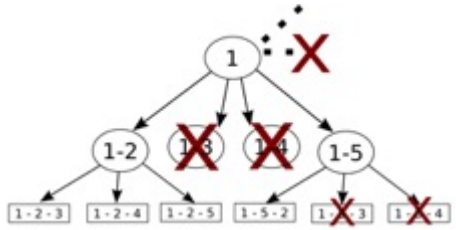
For more about applications of Chapel…



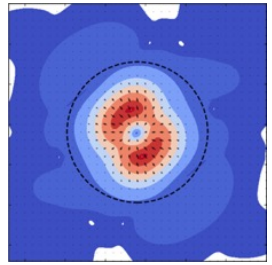
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



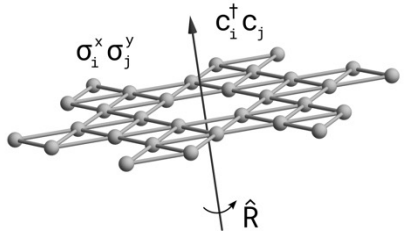
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



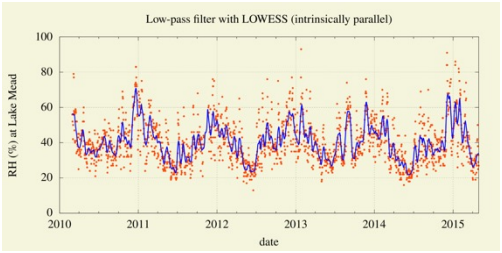
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



ChplUltra: Simulating Ultralight Dark Matter
Nikhil Padmanabhan, J. Luna Zagorac, et al.
Yale University et al.

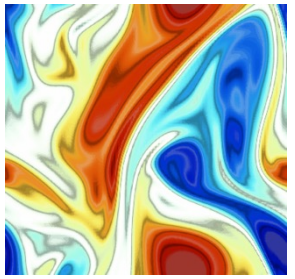


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

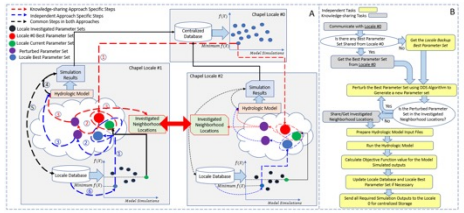


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

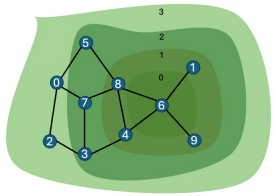
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



ChapQG: Layered Quasigeostrophic CFD
Ian Grooms and Scott Bachman
University of Colorado, Boulder et al.

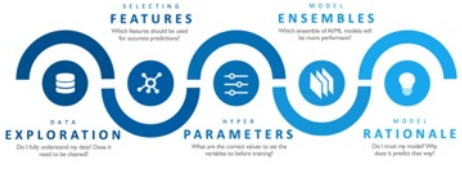


Chapel-based Hydrological Model Calibration
Marjan Asgari et al.
University of Guelph



Arachne Graph Analytics
Bader, Du, Rodriguez, et al.
New Jersey Institute of Technology

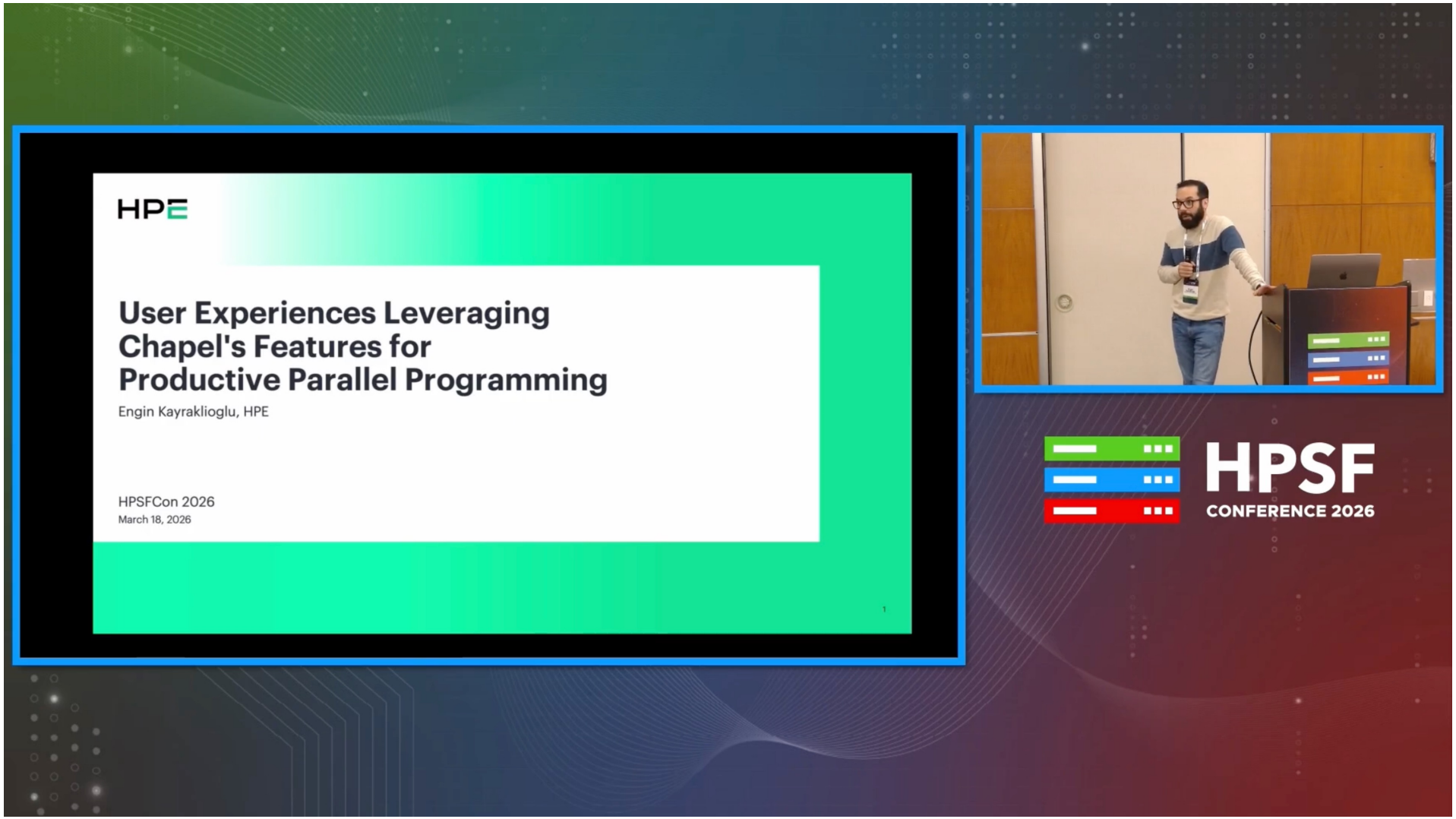
Modeling Ocean Carbon Dioxide Removal
Scott Bachman Brandon Neth, et al.
[C]Worthy



CrayAI HyperParameter Optimization (HPO)
Ben Albrecht et al.
Cray Inc. / HPE

[images provided by their respective teams and used with permission]

...see Engin Kayraklioglu's HPSFCon 2026 talk



https://chapel-lang.org/presentations/#artifact-hpsfcon26-users

…or our “7 Questions for Chapel Users” Interview Series

Chapel’s proven to be generally applicable & attractive for:

- Computational Fluid Dynamics
- Earth Sciences
- Exploratory Data Analytics
- Astrophysics
- Graph Analysis
- Artificial Intelligence
- …

Chapel Language Blog

About Chapel Website Featured Series Tags Authors All Posts

7 Questions for Scott Bachman: Analyzing Coral Reefs with Chapel

Posted on October 1, 2024.

Tags: Earth Sciences | Image Analysis | GPUs | User Experiences | Interviews

7 Questions for Éric Laurendeau: Computing Aircraft Aerodynamics in Chapel

Posted on September 17, 2024.

Tags: Computational Fluid Dynamics | User Experiences | Interviews

7 Questions for Akihiro Hayashi: Early Chapel GPU Support through Multiresolution Abstractions

Posted on March 18, 2026.

Tags: GPUs | User Experiences | Interviews | ChapelCon

7 Questions for David Bader: Graph Analytics at Scale with Arkouda and Chapel

Posted on November 6, 2024.

Tags: Graph Analytics | Arkouda | User Experiences | Interviews

7 Questions for Bill Reus: Interactive Supercomputing with Chapel for Cybersecurity

Posted on February 12, 2025.

Tags: Data Analysis | Arkouda | User Experiences | Interviews

7 Questions for Tiago Carneiro and Guillaume Helbecque: Combinatorial Optimization in Chapel

Posted on July 30, 2025.

Tags: Searching / Sorting | GPUs | User Experiences | Interviews

7 Questions for Marjan Asgari: Optimizing Hydrological Models with Chapel

Posted on September 15, 2025.

Tags: Earth Sciences | User Experiences | Interviews

7 Questions for Oliver Alvarado Rodriguez: Exploiting Chapel’s Distributed Arrays for Graph Analysis through Arachne

Posted on January 21, 2026.

Tags: Graph Analytics | Arkouda | Sparse Arrays | User Experiences | Interviews

By: Engin Kayraklioglu, Brad Chamberlain

Part of a series: 7 Questions for Chapel Users

7 Questions for CHAMPS Developers: Empowering Academic R&D to Create Cutting-Edge CFD Apps in Chapel

Posted on March 26, 2026.

Tags: Computational Fluid Dynamics | User Experiences | Interviews

By: Engin Kayraklioglu, Brad Chamberlain

Part of a series: 7 Questions for Chapel Users

7 Questions for Nelson Luís Dias: Atmospheric Turbulence in Chapel

Posted on October 15, 2024.

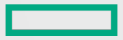
Tags: Earth Sciences | Computational Fluid Dynamics | User Experiences | Interviews | Data Analysis

By: Engin Kayraklioglu, Brad Chamberlain

Part of a series: 7 Questions for Chapel Users

https://chapel-lang.org/blog/series/7-questions-for-chapel-users/

Closing Thoughts



AI and Parallel Languages

Q: Now that AIs can program*, do languages like Chapel still have value?

(* = your mileage may vary)

A: I'd say "definitely", at least for the foreseeable future:

- Targeting a single, unified parallel language should be at least as successful as a mash-up of lower-level notations
- Leveraging higher-level abstractions and compiler optimizations conserves tokens by not re-solving problems
- As long as humans need to validate and maintain AI-developed code, the clearer it is the better

Chapel

```
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

SHMEM (Exstack version)

```
i=0;
while( exstack_proceed(ex, (i==l_num_req)) ) {
  i0 = i;
  while(i < l_num_req) {
    l_indx = pckindx[i] >> 16;
    pe   = pckindx[i] & 0xffff;
    if(!exstack_push(ex, &l_indx, pe))
      break;
    i++;
  }

  exstack_exchange(ex);

  while(exstack_pop(ex, &idx , &fromth)) {
    idx  = ltable[idx];
    exstack_push(ex, &idx, fromth);
  }
  lgp_barrier();
  exstack_exchange(ex);

  for(j=i0; j<i; j++) {
    fromth = pckindx[j] & 0xffff;
    exstack_pop_thread(ex, &idx, (uint64_t)fromth);
    tgt[j] = idx;
  }
  lgp_barrier();
}
```

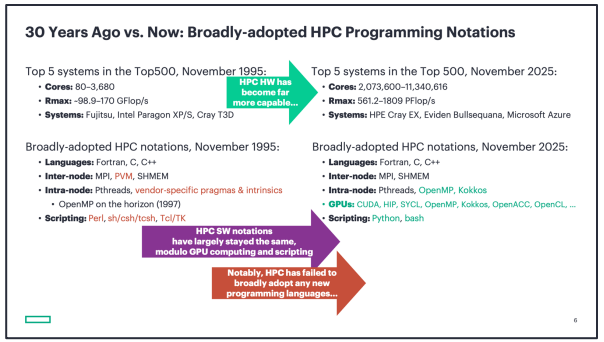
SHMEM (Conveyors version)

```
i = 0;
while (more = convey_advance(requests, (i == l_num_req)),
       more | convey_advance(replies, !more)) {

  for (; i < l_num_req; i++) {
    pkg.idx = i;
    pkg.val = pckindx[i] >> 16;
    pe = pckindx[i] & 0xffff;
    if (! convey_push(requests, &pkg, pe))
      break;
  }

  while (convey_pull(requests, ptr, &from) == convey_OK) {
    pkg.idx = ptr->idx;
    pkg.val = ltable[ptr->val];
    if (! convey_push(replies, &pkg, from)) {
      convey_unpull(requests);
      break;
    }
  }

  while (convey_pull(replies, ptr, NULL) == convey_OK)
    tgt[ptr->idx] = ptr->val;
}
```

Summary

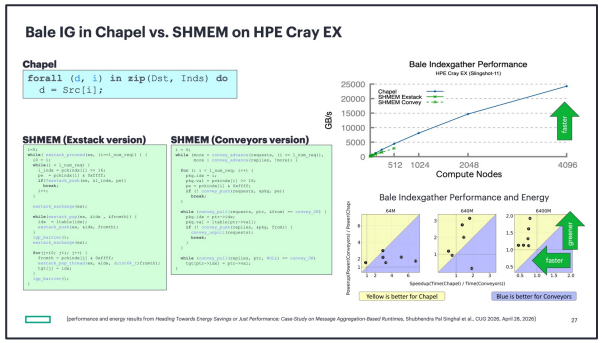
Parallel programming traditionally requires a mix of notations to leverage HW

- e.g., C++ with MPI, OpenMP, and/or CUDA
- such programming models are sufficient, but leave much to be desired
- hardware has generally become more difficult to program over time
  - and at HPC scales, hardware speeds & feeds tend to dominate budgets and attention



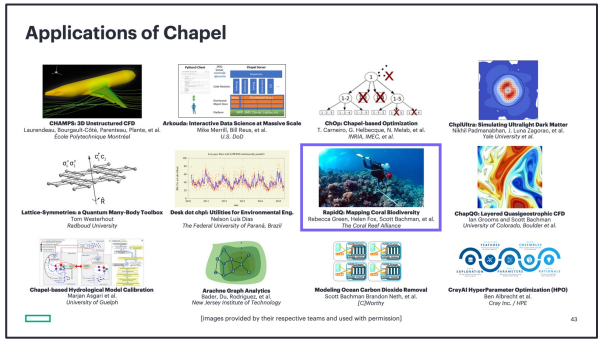
Chapel is a unique programming language

- high-level features for parallelism and locality
- portable across CPUs, GPUs, networks, vendors, scales, …
- scalable, performant, energy-efficient
- simplifies compiler optimizations on distributed systems (not discussed today)

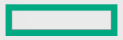


Users are benefitting from Chapel, on laptops as well as supercomputers

- Exploratory Data Analysis
- Computational Fluid Dynamics
- Coral Reef image processing
- …



Chapel Resources



Ways to engage with the Chapel Community

Synchronous Community Events

- Project Meetings, weekly
- Deep Dive / Demo Sessions, weekly timeslot
- ChapelCon (formerly CHIUW), annually

Asynchrounous Communications

- Chapel Blog
- Community Newsletter, quarterly
- Announcement Emails, around big events

Social Media

FOLLOW US

- BlueSky
- Facebook
- LinkedIn
- Mastodon
- Reddit
- X (Twitter)
- YouTube

Discussion Forums

GET IN TOUCH

- Discord
- Discourse
- Email
- GitHub Issues
- Gitter
- Slack
- Stack Overflow

Ways to Use Chapel

GET STARTED

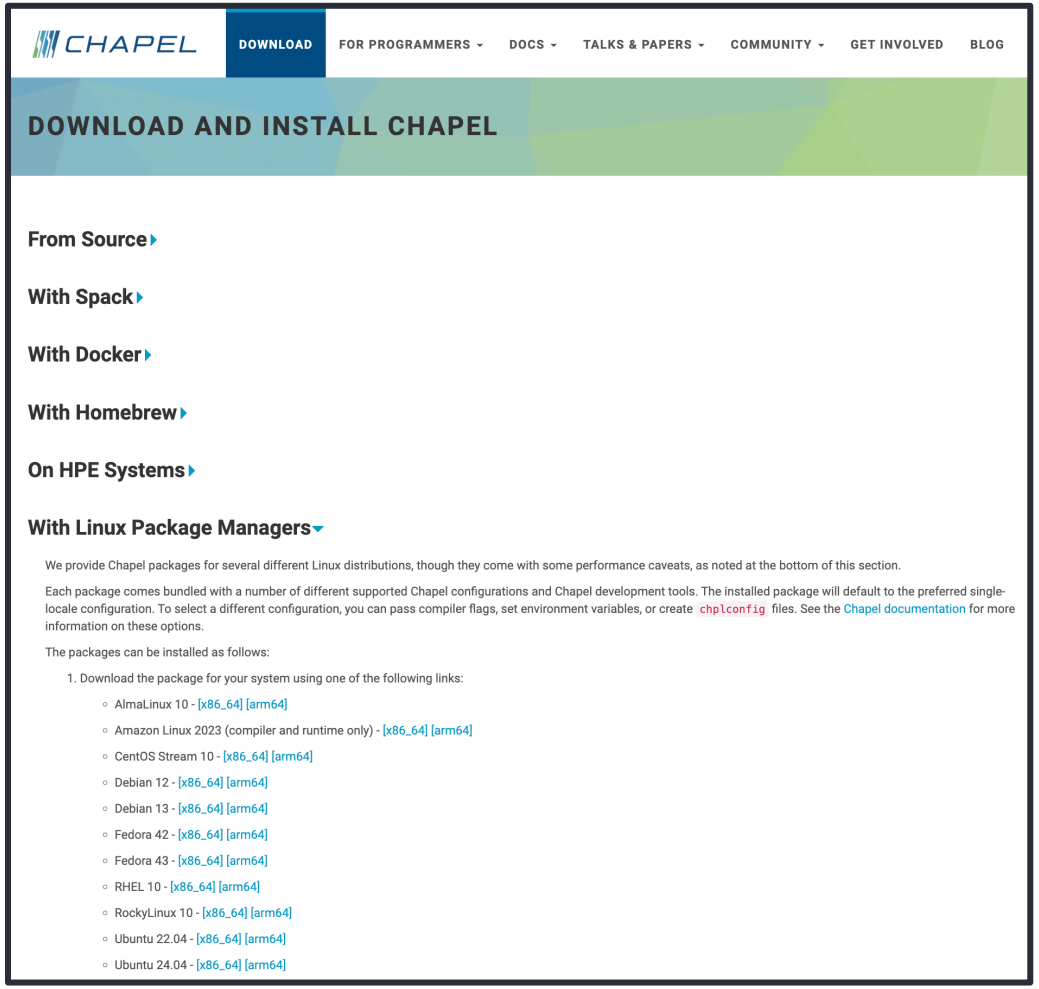
- Attempt This Online
- Docker
- E4S
- GitHub Releases
- Homebrew
- Spack

(from the footer of chapel-lang.org)

Where can I get Chapel?

Release Formats:

— Source releases via GitHub
— Spack / E4S
— Docker
— Homebrew
— Linux packages via apt/rpm
— Modules on HPE Cray systems
— Attempt This Online / GitHub Codespaces



https://chapel-lang.org/download/

Where Does Chapel Run?

In the Browser:
- Attempt This Online (ATO)
- GitHub Codespaces

Laptops/Desktops:
- Linux/UNIX
- Mac OS X
- Windows (leveraging WSL)

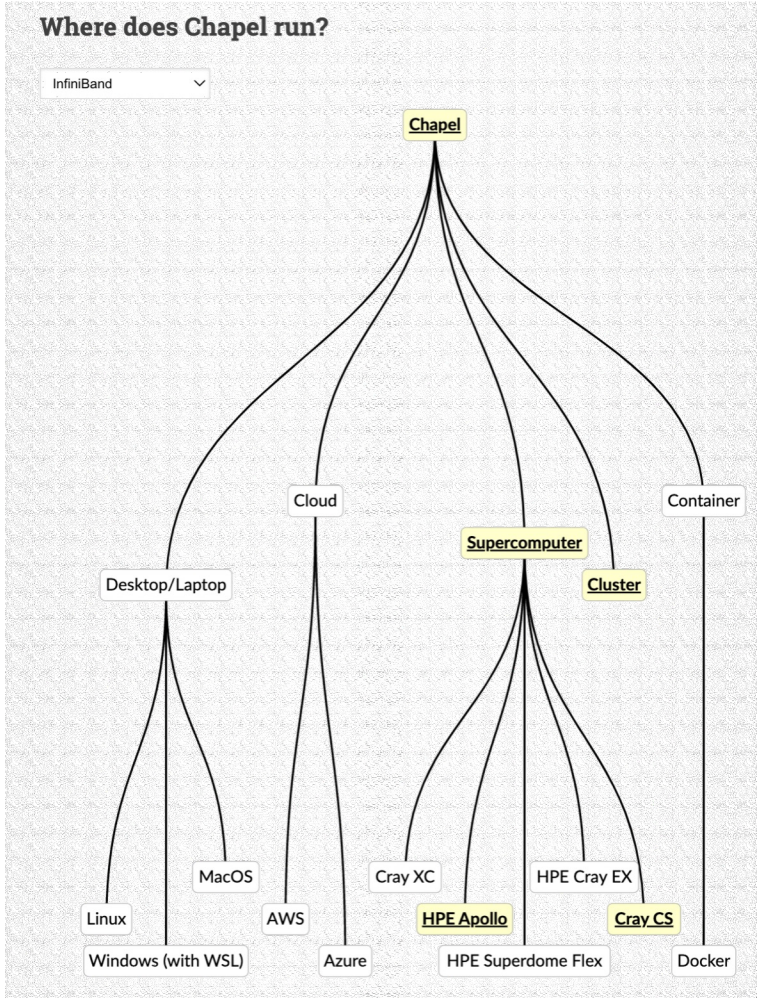
HPC Systems:
- Commodity clusters
- HPE/Cray supercomputers, such as:
  - Frontier
  - Perlmutter
  - Piz Daint
  - Polaris
  - …
- Other vendors' supercomputers

Cloud:
- AWS
- Microsoft Azure (?)
- Google Cloud (?)

CPUs:
- Intel
- AMD
- Arm (M1/M2, Graviton, A64FX, Raspberry Pi, …)

GPUs:
- NVIDIA
- AMD

Networks:
- Slingshot
- Aries/Gemini
- InfiniBand
- AWS EFA
- Ethernet



https://chapel-lang.org/docs/usingchapel/portability.html

Thank You

@ChapelLanguage